Neuromuscular activity of trunk muscles during side plank exercise and an additional motoric-task perturbation

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Neuromuscular Activity of Trunk Muscles during Side Plank Exercise and an Additional Motoric-Task Perturbation

Neuromuskuläre Aktivität des Rumpfes beim Seitstütz mit und ohne motorische Perturbations-Aufgabe

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Summary

- **Problem:** Core-specific sensorimotor exercises (CSSE) combined with technically applied unexpected high-intensity perturbations (UHIP) are able to enhance neuromuscular activity of the trunk muscles (TM). Since including UHIP into clinical practice is complicated, it is warranted to implement a feasible perturbation task. Aim of the study was to analyze the effects of an additional motoric-task perturbation on trunk neuromuscular activation pattern during CSSE exercise.
- **Methods:** Ten participants (5m/5f; 29±2years; 177±7cm, 74±12kg) were included and prepared with a surface EMG-setup for trunk muscles. EMG-data were collected during a side plank on stable surface (SP; 30sec) and randomly in 3 different conditions: adding a pad under the right elbow (SPP), adding a perturbation task (SP+P) and adding pad and perturbation task (SPP+P). Root mean square (RMS) was calculated for the whole exercise cycle (30sec) and normalized to MVIC (%MVIC). Muscles were grouped to ventral (VR; VL) and dorsal (DR; DL) right/left. In addition, the ratios of Ventral:Dorsal (V:D) and Side-Right:Side-Left (SR:SL) were calculated. Differences between conditions were assessed for muscle groups and ratios (repeated-measures ANOVA; α=0.05).
- **Results:** SPP+P showed the highest EMG-RMS for all muscles except DL, showing significant differences between conditions SP and SP+P in VR and VL, respectively. No differences ($p<0.05$) were found between SPP and SPP+P, SP+P. Ratios revealed no significant differences between conditions.
- **Discussion:** The additional motoric-task perturbation during a CSSE significantly enhanced trunk neuromuscular activity.

Zusammenfassung

- **Problem:** Rumpf-spezifische sensomotorische Übungen (CSSE) in Kombination mit unerwarteten hochintensiven Perturbationen (UHIP), die mit technischen Hilfsmitteln appliziert wurden, verstärken die neuromuskuläre Aktivität der Rumpfmuskulatur (TM). Da es schwierig ist, UHIP in die klinische Praxis zu integrieren, erscheint es notwendig eine machbare motorische Perturbations-Aufgabe zu implementieren. Ziel der Studie war es, die Auswirkungen einer zusätzlichen motorischen Perturbations-Aufgabe auf das neuromuskuläre Aktivierungsmuster des Rumpfes während des Seitstütz auf stabilem und instabilem Untergrund zu analysieren.
- **Methoden:** Zehn Teilnehmer (5m/5w; 29±2 Jahre; 177±7cm, 74±12kg) wurden eingeschlossen und mit einem 12-Kanal Oberflächen-EMG am Rumpf präpariert. Das EMG wurde während des Seitstütz (30sec.) auf einer stabilen Oberfläche (SP) sowie randomisiert unter drei verschiedenen Bedingungen erfasst: Ausführung auf instabilem Untergrund (SPP), Ausführen einer Perturbationsaufgabe auf stabilem Untergrund (SP + P) und Ausführen einer Perturbationsaufgabe auf instabilem Untergrund (SPP + P). Der EMG-RMS (Root Mean Square) wurde für den gesamten Übungszyklus (30 Sekunden) berechnet und auf die individuelle maximale isometrische Kontraktion (% MVIC) normalisiert. Die Muskeln wurden nach ventral (VR; VL) und dorsal (DR; DL) rechts/links gruppiert. Zusätzlich wurden die Verhältnisse von Ventral: Dorsal (V: D) und Side-Right: Side-Left (SR: SL) berechnet. Die Unterschiede zwischen den Bedingungen wurden für die Muskelgruppen und -verhältnisse analysiert (ANOVA für wiederholte Messungen; α=0,05).
- **Ergebnisse:** SPP+P zeigte den höchsten EMG-RMS für alle Muskeln außer DL und zeigte signifikante Unterschiede zwischen den Bedingungen SP und SP+P in VR bzw. VL. Es wurden keine Unterschiede ($p<0,05$) zwischen SPP und SPP+P, SP+P gefunden. Die Verhältnisse zeigten keine signifikanten Unterschiede zwischen den vier Konditionen.
- **Schlussfolgerungen:** Durch die zusätzliche Perturbation in Form einer motorischen Zusatzaufgabe während einer rumpf-spezifischen Übung (Seitstütz) wurde die neuromuskuläre Aktivität des Rumpfes signifikant erhöht.

KEY WORDS:
EMG, Sensorimotor Training, Core-Stability, Instability, Trunk Exercise

SCHLÜSSELWÖRTER:
EMG, sensomotorisches Training, Rumpfstabilität, Instabilität, Rumpfübung

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Problem and Objectives

Adequate neuromuscular response of the trunk muscles (TM) is considered to be of great importance in sport performance, as well as for activities of the daily living (3, 5, 9, 12). Particularly, trunk muscles are responsible for body segment stabilization in many common daily-life activities (lifting objects, walking, running) (3, 9, 12, 25). It is evident that, neuromuscular patterns such as muscular activity, coordination, response time as well as strength will protect the trunk from repetitive and high unexpected overload (5).

Table 1

Exercise conditions: SP=stable; SPP=unstable; SP+P=perturbation task; SPP+P=unstable+perturbation task; Δ=absolute value of RMS difference between condition (%MVIC); *=significant differences (p<0.05) Bonferroni adjusted.

	SP VS SPP		SP VS SP+P		SP VS SPP+P		SPP VS SP+P		SPP VS SPP+P		SP+P VS SPP+P	
	Δ	*p*	Δ	*p*	Δ	*p*	Δ	*p*	Δ	*p*	Δ	*p*
VR	27.78	0.008*	20.38	0.010*	38.65	<0.001*	7.40	1.000	10.87	0.486	18.26	0.002*
VL	5.67	0.009*	5.17	0.019*	11.97	0.013*	0.49	1.000	6.30	0.442	6.80	0.079
DR	13.80	0.163	9.47	1.000	18.06	0.196	4.31	1.000	4.27	1.000	8.60	0.011*
DL	9.48	0.468	2.81	1.000	6.79	0.118	6.64	1.000	2.68	1.000	3.98	0.703

Core-specific sensorimotor exercises (CSSE) are an effective method to improve neuromuscular activity of the trunk muscles and consequently improve core stability (1, 16, 17). Sensorimotor training emphasizes an activation of deep trunk muscles (10), enhancing muscle control and restoring inter/intra muscular coordination (21). In advanced stages, the execution of more functional tasks required activation of both deep and global trunk muscles (10, 23) and implementing unstable training devices (e.g. foam pad, wobble board) ensure higher neuromuscular activation (5, 17). Among several CSSEs, side bridge exercises performed in different instability conditions, elicited greater neuromuscular activation of both deep and superficial muscles stabilizing the trunk (7) and positively correlated with athletic performance (11). This is possible since a higher level of instability corresponds to an increased demand for stabilizing processes, meaning an elevated activity (amplitude) of the related muscles (13, 24) and therefore a higher training effect. The neuromuscular system adapts very quickly to the given applied instability and a consequent instability-progression is necessary to maintain a high level of difficulty in the training situation.

Recent studies included unexpected perturbations into sensorimotor exercises and investigate relative changes in training effect. It was pointed out that perturbations are an effective tool to elicit greater muscular activation (1, 5, 16). Several authors (4, 5, 6) reported that postural manipulations in combination with elastic resistance and/or unstable conditions (e.g., surfaces, devices) elicit increased core muscle activity. Mueller et al. (16) demonstrated that instrumented high-intensity perturbations combined with unstable surfaces (foam pad) during CSSE, increased neuromuscular activity of the trunk muscles. However, the transfer to the practical daily training routine is critical since these instrumented perturbations are applied by a specially designed split-belt treadmill. This requires high costs (device, location) and trained staff. Therefore, easily applicable perturbations (e.g. Tera-Band, researcher induced) are necessary for daily practice in training, rehabilitation and prevention.

Thus, it is warrant to implement an additional, feasible, perturbation task (e.g. motoric-task) to combine to CSSE that will elicit enhanced trunk muscle activity.

Therefore, the aim of the study was to assess the effects of an additional motoric-task perturbation during CSSE (side-plank) on trunk neuromuscular activation patterns. It was hypothesized that performing the side-plank on an unstable surface with an additional motoric-task perturbation would lead to higher trunk muscular activity.

Material and Methods

Ten trained individuals participated in this cross-sectional study (5m/5f; 29±2 year; 177±7cm, 74±12kg; ≥2 sport-session/week). Exclusion criteria were: presence of musculoskeletal pain, low back pain score > 1 on NRS scale (20), neuromuscular disorders, joint or bone disease, acute inflammation/infection, heart diseases and pregnancy. All participants signed a written informed consent after being informed in detail about the study aims and before starting the protocol. The Institution ethical committee approved the study. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

First, anthropometrical data were collected, followed by participants rating of current low-back pain on a NRS scale (0=no pain to 10=maximum imaginable pain). This was followed by skin preparation for surface electromyography (EMG) trunk measurements (22). Twelve pairs of EMG disc electrodes (AMBU Medicotest, Denmark, Type N-00- S; 2 cm inter-electrode) were positioned over 6 abdominal and 6 back muscles along with muscle fiber orientation (16, 17, 18).

Next, after a trunk warm-up, a maximal voluntary isometric contraction (MVIC) on an isokinetic dynamometer device (Contrex MJ_TP; Physiomed Elektromedizin AG, Germany) was performed (2, 19). Participants performed two sessions (5-seconds) of trunk isometric (17.5° trunk flexion) flexion and extension at sub-maximum (practice trial) and maximum (MVIC; EMG recorded) effort each. The collected data were used for an EMG-normalization procedure.

At last, each individual performed the side-plank in four different conditions for 30 sec. First condition was the side-plank (Figure 1) on right body side over a stable surface (SP). The three other conditions were randomly ordered and consisted on: adding a foam pad (Airex BalancePad; ARTZT, Dornburg, Germany) under the right elbow (SPP=unstable), carrying out a motoric-perturbation task (SP+P=perturbation task) and a combination of them (SPP+P=unstable+perturbation task). Exercises SP and SPP were performed as 30 seconds of isometric position, while EMG was recorded, after a familiarization trial (10 sec; 1 minute rest). For SP+P and SPP+P, after a test trial (5 reps.; 1 min rest) at a start signal, when in side plank position, participants performed the motoric-task (EMG recorded) till stop signal (30 sec). This consisted on let roll a tennis ball from the left hand to the left foot, stop the ball and than roll it back to left hand. Individuals were instructed to perform at moderated velocity (≈4 sec).

The following trunk muscles were investigated: rectus abdominis (RA), obliquus externus abdominis (EO), obliquus internus abdominis (IO), erector spinae thoracic (T9; UES)/lumbar (L3; LES) and latissimus dorsi (LD). EMG data were collected with a frequency set of 4000Hz, analyzed using bilateral and bipolar surface telemetry EMG (RFTD-32, myon AG, Baar, Switzerland). Electrode placement was defined using Radebold et al. method (21) and inter-electrode impedance was <5kΩ. With an accelerometer an investigator triggered start and stop of every exercise duration. Acquired EMG-data were rectified

Figure 1

Perturbation task: motoric task, moving ball continuously from hand to foot and vice versa. SP=Side plank stable surface, SPP=SP unstable surface; SP+P=SP + perturbation task; SPP+P=SP unstable + perturbation task.

then amplitudes normalized to MVIC for the whole exercise (30sec) and root mean square (RMS) calculated for each condition. MVIC was obtained as suggested by Mueller et al. 2018 (16). Additionally, four muscle groups were created: right ventral (VR: RA, EO, IO of right side); left ventral (VL: RA, EO, IO of left side); right dorsal (DR: UES; LES, LD of right side) and left dorsal (DL: UES, LES, LD of left side) (14). Each group represented the average (normalized) EMG-RMS of the three included muscles and was reported as %MVIC. Differences between conditions were calculated for each muscle group. Furthermore ratios were calculated for Ventral(VR+VL)/Dorsal(DR+DL) (V:D) and Side-Right(VR+DR)/Side-Left(VL+DL) (SR:SL) muscle groups in each condition.

After a plausibility check, statistical data analysis was performed (SPSS Inc., Chicago, IL, USA, Version 21.0) including means and standard deviations (SD). Normality was tested (Shapiro–Wilk) and due to mixed normal/non-normal distribution, differences between conditions for each muscle group (VR, VL, DR, DL) were assessed by a one-way repeated measures test of variance (ANOVA; $p< 0,05$; Bonferroni adjusted α=0.0125) (8).

Results

Overall, conditions with altered stability (SPP, SP+P, SPP+P), showed an increased mean EMG-amplitude compared to the stable SP. In particular, SPP+P showed the highest values for all muscle groups (VR: 81±7%; VL: 17±3%; DR: 55±8%) except for the dorsal left (DL: 34±6%; %MVIC±SD; Fig. 2). Exercise condition on stable surface (SP) showed the lowest EMG-RMS values for all muscle groups. When side-plank was performed with the additional perturbation task only (SP+P) lower amplitudes for all muscles groups were detected then for SPP and SPP+P, but higher than side-plank in a stable condition (SP) (Figure 2). Repeated measures ANOVA test revealed significant differences between conditions SP and SPP+P for ventral right and left muscle groups (Table 1). No differences ($p>0.05$) between mean values were found for all muscles groups when comparing condition SPP to SP+P and SPP+P. After ratio coefficient calculations, analysis of differences showed no significance between frontal and dorsal muscles groups ratio (V:D) as well as for side right/left ratio (SR:SL). Amplitudes (mean, %MVIC) for all 12 trunk muscles over the four conditions are reported in the polar-plot (Figure 3).

Discussion

The objective of this study was to assess the effect of an additional perturbation task (P) on trunk muscle activity when performing a CSSE (side-plank) on a stable and unstable surface. The study results are in line with current literature, where it's known that muscle activity in the trunk muscles and lower extremities increases at higher levels of instability (5, 16, 24, 25). Side-plank exercise in the four different analyzed conditions, provided a gradual increase in neuromuscular trunk activity with possible positive effect on training efficiency (13, 25). The high demand represented by maintaining balance when performing exercise on unstable surfaces, and/or under perturbation conditions, indicate an increased core muscle activity promoting trunk muscle coordination (24). The four different conditions investigated and their correspondent trunk muscle activity, could be then ordered in a progression line (stable= less activation → instable + perturb. task=high activation) from the easiest to the most difficult exercise. This is in line with a previous study (16) that demonstrated the efficacy of sudden technically-based high intensity perturbations to enhance core muscles activity. Relevant for therapists is that similarly, the proposed additional perturbation task (motoric task) was effective to enhance neuromuscular activity of the core stabilizers and could be easily implemented in a clinical practice routine.

Looking at the four different muscle groups (VR, VL, DR, DL) and their relative %MVIC, the greater activation of right-sided muscle groups was expected, since supporting the body weight in the side-plank position is eliciting a greater involvement of the related side musculature. This is particularly evident for the SPP+P condition, where the mean neuromuscular activity

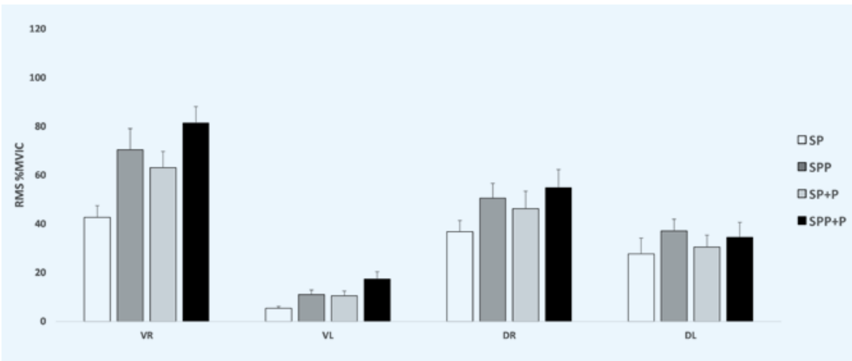

Figure 2

Neuromuscular activity (RMS: %MVC; mean±SD) for all four muscle groups for all three exercise conditions. Muscle groups: VR=ventral right; VL=ventral left; DR=dorsal right; DL=dorsal left. Exercise conditions: SP=stable; SPP=unstable; SP+P=perturbation task; SPP+P=unstable + perturbation task.

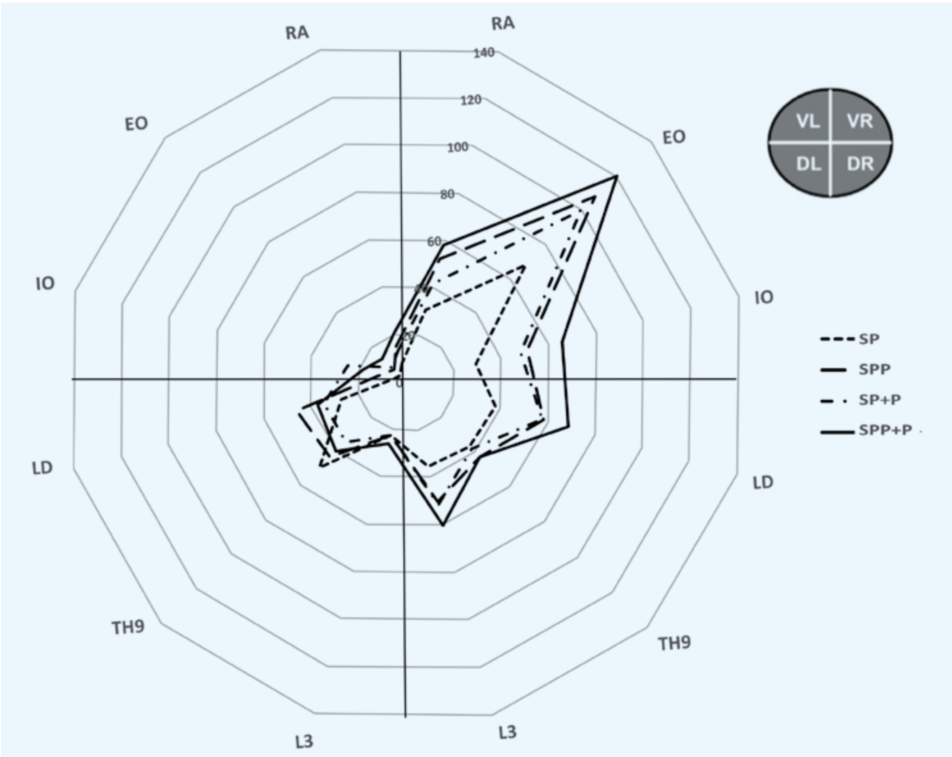

Figure 3

Polar-plot of neuromuscular activity (RMS: %MVC; mean) pattern of all 12 single trunk muscles for all conditions. Exercise conditions: SP=stable; SPP=unstable; SP+P=perturbation task; SPP+P=unstable + perturbation task.

of ventral right muscles reached 80% of MVIC. For the ventral and dorsal right group (VR, DR) a marked progression in neuromuscular activation levels is observable, starting from the lower (SP) to the higher (SPP+P) activation levels (SP→SP+P→SP-P→SPP+P). This pattern reflects an easy-to-complex exercise progression (SP=easy → SPP+P=complex) resulting of great importance to implement a progressive escalation in difficulty/muscular activation in training protocol.

The ventral left trunk muscles (VL) reported the lowest mean values in all conditions ranging between 5 and 17% of MVIC only. This could be due to exercise position, counting the ventral left muscles as a secondary trunk/hip stabilizer (body straight alignment) and without needing to lift body weight. This is particularly evident in the stable condition (SP). Introducing instability (SPP) and/or a perturbation task (SP+P, SP-P+P), neuromuscular activity level rises significantly meaning a greater demand for stabilization. The muscle group dorsal left (DL) displayed a small variation between the means of each exercise conditions, ranging from 28 to 37%MVIC maximum when adding the foam pad (SPP). We can infer, that these muscles were recruited slightly (<50%MVIC) in a side-plank position with similar neuromuscular activation levels, regardless of condition.

At last, based on the presented findings, it is reasonable to say that the chosen motoric perturbation (Fig. 1) was effective in enhancing trunk muscle activity. The task was performed actively by the individual and it presented a combination of unexpected/expected stimuli, since a continuous visual feedback to the ball was possible. On the other side, since the task was performed in an unusual body position with altered body balance, ball trajectory was unexpected with consequent continuous posture-adaptation to reach the ball (resulting in sudden body sway).

A few considerations have to be made on methodological limitations. A kinematic analysis of the possible compensation patterns, especially during perturbation task, might help to clarify different levels of muscle activation between the different groups (VR; VL; DR; DL). Application of functional tests for each single muscle might lead to a difference in MVIC amplitude, instead of the selected standardized test on an isokinetic dynamometer (19). A relatively small cohort was investigated, therefore a transfer to a bigger and different population (e.g. low back pain patient) should be considered. At last, only a side-plank exercise was assessed. Different CSSE and other methods to apply perturbations should be further investigated. Further investigation should take in account a different population (e.g. low back pain patients) and greater sample size.

The results demonstrated that the use of an additional perturbation task in combination with an unstable surface is superior to enhance trunk neuromuscular activation during the side-plank exercise. It's evident that an increase in exercise instability (instability + perturbation task), will produce an increase of core muscle activity representing an enhanced training efficiency. Furthermore, the simple motoric perturbation task observed, offers a potential insight for therapists, who might implement training protocols addressing the core musculature.

Conflict of Interest

The authors have no conflict of interest.

Founding

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